

LED Jitter-Induced Limitation Effects in the Baud Rate of VLC Systems

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Abstract- In this paper we show that the effect of jitter due to driver and LED is the limiting factor in the baud rate in L-PPM formats for VLC systems.

I. INTRODUCTION

Visible Light Communication (VLC) is a new type of optical communication using lamps based on LEDs [1]. Usually two modulation schemes are used: one for establishing the illumination level (usually PWM), and a second for transmitting the data (any flavor of PPM). The switching ON and OFF of the LEDs should be fast enough for avoiding light flickering, fixing the lower frequency limit at several hundred of Hz. On the other side, a high data rate imposes high switching frequencies (some MHz).

Other modulating methods have been proposed [2], but they are not suitable in real illumination systems due to light flickering, optical power level, light fluctuations dependence of the data transmitted, and electrical efficiency of the driver [3]. Unfortunately, high power visible LEDs have rise and fall times in the range of 100 ns (400 ns for white phosphor LEDs), so the ON and OFF states require long pulses. The ratio between the ON and OFF times, controlled by PWM, determinates the illumination level of the lamp.

L-PPM schemes can improve the data rate using multi-bit symbols. Notice that only the rising (or falling) edge can be used for data transmission, because the other one is fixed by the duty cycle corresponding to the illumination level. Due to the long optical pulses, the technique of Overlapping PPM (OPPM) is the most suited for these systems [4].

Under these constraints (long optical pulses and high data rates), the limiting factor for the number of symbols (L) in L-OPPM is the allowable precision of the timing of the pulses edges, i.e. the jitter of the received signal.

II. DESCRIPTION

For simplicity, we use a very simple L-OPPM scheme, which is not intended to be the optimum for achieving high data rates. Nevertheless, the conclusions can be applied to other PPM schemes. Also, a fixed Duty Cycle (DCy), i.e. illumination level, is used, so the ratio between the light pulse duration and the period of the PWD signal is constant. An adjustable DCy would require longer descriptions for covering different limit cases [5].

In figure 1, the parameters used in the analysis are presented. A guard time (T_{min}) is required for the falling edge

of the pulse, before the end of the symbol period.

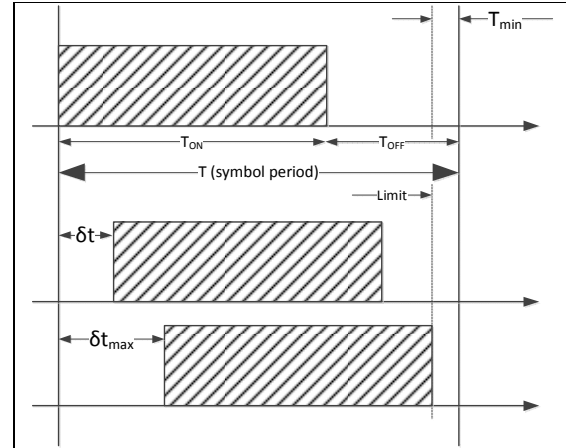


Figure 1. Optical pulse position inside the symbol period

The data is encoded by the pulse delay (δt). In L-PPM, δt_{max} is divided in L time slots, usually a power of 2, and the data is encoded by placing the rising edge of the pulse in the n th slot. The receiver measures the delay and assigns a set of bits to the impulse detected. Clearly, the system efficiency increases with the number of slots: a single symbol (pulse) transmits more bits. The number of slots is limited by the time noise, i.e. jitter, of the received signal.

The jitter on the receiver includes three sources: first, the fluctuations of the LED switching caused by the own LED and its driver circuit; second, the multipath response of the light traveling between the emitter and the receiver; and third, the jitter induced by the noise (usually thermal) of the receiver.

The second factor, the multipath dispersion, is usually negligible, because the room response only changes very slowly, corresponding to small displacements (compared with the symbol period) of the receiver [6-7]. Nevertheless, multipath dispersion has an important influence on the rise time of the signal, so the detection threshold of the edge should be modified according the rise time variations.

As the emitted power is high (from several watts to ten of watts), the S/N ratio on the receiver is large, reducing the influence of the third factor (noise induced jitter) [8]. In any case, this effect has been largely studied and precise jitter estimation can be calculated for a given system.

The received signal was analyzed in a digital oscilloscope with a sampling period of 0.25 ns. A cumulative histogram of the crossing the 50% level amplitude was taken. The acquisition of the Red LED is presented in the figure 2. It includes the color assigned number of samples and the parameters of the fitting of the histogram to a Gaussian curve. The results are presented in the Table I. By using the Gaussian

approximation and the rms value of the jitter, the slot time can be designed so as to obtain a given symbol error.

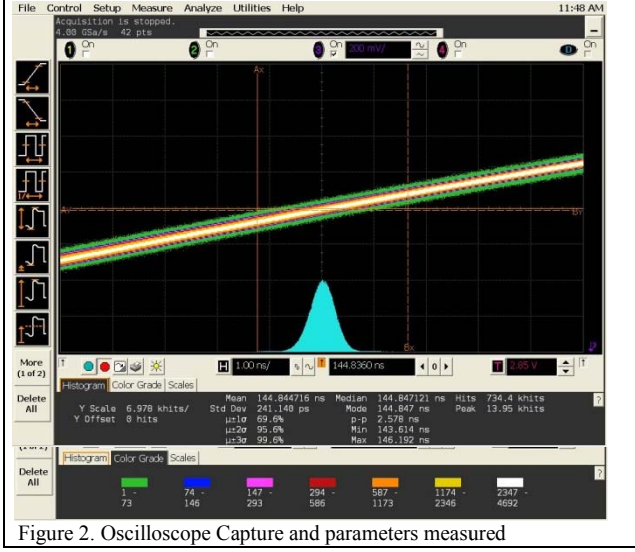


TABLE I. MEASUREMENT RESULTS		
LED*	Rise/fall (ns)	Jitter (ps)
Red	40/81	241
Amber	39/87	492
Green	39/78	392
Blue	29/93	112
Warm White	367/418	1176

III. DISCUSSION AND CONCLUSIONS

From the data in Table I, the slot time can be selected for a given symbol error. The symbol period is:

$$T_{\text{Symbol}} = \frac{1}{1 - DC_y} (T_{\min} + \delta t_{\max}) = \frac{k + 2^N}{1 - DC_y} \epsilon \quad (1)$$

Where: $k = T_{\min} / \epsilon$, $\delta t_{\max} = 2^N \epsilon$,

and ϵ is the selected slot duration, and 2^N is the length of the code (L). The bit rate is:

$$R = \frac{(1 - DC_y) N}{(k + 2^N) \epsilon} \quad (2)$$

The Figure 3 shows the data rates from the data of the red LED using (2). It has been included Manchester encoding for comparison. It is noticeable the strong effect of the duty cycle, which widens the symbol period, and thus reduces the symbol rate.

The fall time is roughly twice the rise time (but in warm white LED, where it is controlled by the phosphor, not electrical carriers lifetimes). This is due to the simple driver circuit used; but a short negative current impulse will reduce this time to values close to the rise time, and so we have used this time as T_{\min} in our calculations.

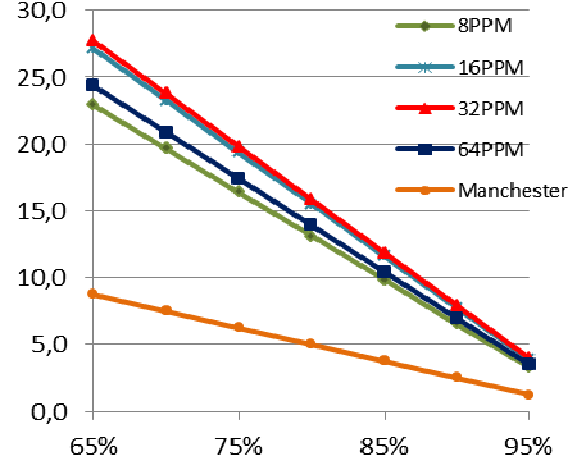


Figure 3. Data Rate (Mbps) vs. DC_y . Parameters corresponding to the Red LED with T_{\min} =rise time, and slot time, $\epsilon=3\sigma$

For a real (efficiency optimized) driver, it should be checked the degradation on the overall efficiency if shorter T_{\min} values are used. In this case, the amplitude of the optical signal is lower, so the reduction of the S/N ratio could affect the noise induced jitter.

In conclusion, for real illumination systems, where the communication performance is constrained by illumination level and energy efficiency, L-OPPM seems to be the best candidate for data transmission as they can be modeled to be more jitter-resistant. Also, the modulating signal can be merged with the control one (PWM) making the driver simpler.

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* 3Watt LEDs model HP-803XX (XX defines the color) from Roithner Lasertechnik GMBH